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LUNAR PHYSICAL PARAMETERS STUDY

PARTIAL REPORT NO. 3

MEASUREMENT OF LUNAR SURFACE ACOUSTIC PROPERTIES - A FEASIBILITY STUDY

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A FEASIBILITY STUDY

October 10, 1960

TEXACO
INC.

RESEARCH AND TECHNICAL DEPARTMENT

EXPLORATION AND PRODUCTION RESEARCH DIVISION

BELLAIRE, TEXAS

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OUTLINE

SUMMARY

This study has indicated that the most feasible acoustic property measurement on the lunar surface would be the compressional wave velocity. Measurement of Rayleigh (surface) wave velocity is considered impractical in this application. The most promising method is that using a pulsed acoustic source and a spread of two acoustic detectors (receivers), over-all span being some 10 to 20 feet.

Laboratory and field tests, and past experiences have indicated that the more desirable source would be a small explosive charge, similar to a dynamite cap or smaller. The explosive charge has the advantages of (1) a short period, (2) high-energy, and (3) wide frequency spectrum. Such a source is especially needed in this application since its design can be essentially independent of the properties of the material to be tested. Field tests in a low velocity, high attenuation, area of the earth's surface using a dynamite cap as source have indicated that spacings on the order of 10 feet to the first detector and 10 feet between detectors should be practical. Shorter spacings could be utilized if the detection and recording system is fast enough to allow good resolution for the measurement in the high velocity materials.

The problems of velocity and intensity of the gas wave from the explosive, in a vacuum, need to be investigated. A study of acoustic decoupling of the S/C and its legs will also be necessary. Laboratory tests indicate that in the practical application the acoustic coupling and transmission problems are essentially unchanged by the presence of vacuum rather than air.

Acoustic detectors to be used would be of the moving-coil geophone type, such as marketed by Hall-Sears, Inc., Houston, Texas. The frequency response of interest would be in the range of 50 or 100 cps as a low end and some 4 KC. as a high end. Amplifiers would have maximum gain available, limited only by acoustic or electrical noise. Some frequency discrimination may be desirable, especially below 100 cps to reduce background acoustic noise problems.

If the problems indicated are satisfactorily solved (and it seems that they can be), the feeling is that the compressional wave velocity on the lunar surface can be measured with reasonable assurance and accuracy.

THEORY

General

Measurements of acoustic velocities in solids have been made using various methods and techniques[1]. Most of these require samples having finite and known dimensions, and of low-acoustic-loss materials. The common method of measuring acoustic velocity of the near-surface materials of the earth, in place, is that utilizing a pulsed acoustic source and one or more acoustic detectors placed in line along the acoustic travel path.

This method is used with many variations and techniques, but the essential requirements are similar. Some type of "pulsed" source of acoustic energy located on, or near, the surface is utilized. A measurement of the travel-time for the acoustic energy from the source to a single detector normally offers the simplest arrangement. However, this measurement may be very inaccurate (due to errors in detecting the start of the acoustic pulse at the source and in detecting the "first-arrival" energy at the detector) unless the travel path between source and detectors is long (several wave lengths desirable). A more satisfactory arrangement is to utilize two (or more) detectors placed apart and in-line (preferably) with the direction of travel of the acoustic wave from the source. The spacing between detectors divided by the difference in arrival times is a measure of velocity. The time of start of the energy source is not critical (except that the recording apparatus needs to be in operation sometime before energy arrives at the first detector and preferably before the source is pulsed) and the difference in travel time to the two detectors can generally be measured more accurately than that to a single detector, especially when signal quality is poor.

Velocity measurements have been made using earthquakes as sources, with signal frequencies of a few c.p.s. and lower, and spacings in the order of tens of miles and more. Also, explosives are commonly used as sources with signals having frequencies in the range of a few hundred c.p.s. and lower, and spacings in the order of hundreds of feet. In most cases, the spacings are chosen based primarily on the wavelength of the predominant signals to be detected. Many other parameters determine this choice however, such as source energy available, signal attenuation (especially with frequency) in the material, and resolution of the detecting and recording equipment.

In the "ideal" case, (and in many practical cases on earth where optimum source and spacings are available), one can measure both the compressional (P) wave velocity and the Rayleigh (R or Surface) wave velocity with the pulsed-source-multiple-detector system. Figure 1 demonstrates the "ideal" case. Here, even the shear (S) wave velocity can be estimated. This representation was made on a two-dimensional laboratory model using lucite as the sample. The time-scale is indicated by 10, 50, and 100 µsec. markers, and the spacing between adjacent detectors was 1/2 inch, with the first detector placed 1" from the source. The predominant frequency of the

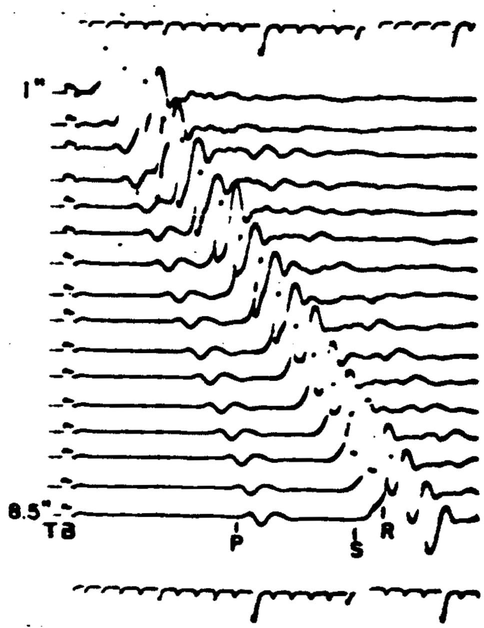

FIGURE 1

DIRECT WAVE REPRESENTATION

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1:794-3

source was approximately 100 KC. All waves shown are direct waves (those traveling the direct path from source to detector). The relation between P, R_1 and S wave velocities can be found in various texts[2].

Unfortunately, the field problem usually departs from this example in several ways. The material is not normally homogeneous, neither laterally nor with depth; the energy source does not offer as "clean" a pulse; the number of detectors and their location are usually more limited; the various types of waves may "override" each other; the range of amplitudes and velocities to be expected is large when properties of the material are unknown. These and other problems with the lunar test dictate that the P wave velocity be the primary objective in the acoustic measurement. However, if one could obtain either of the other wave velocities along with the P wave velocity, the elastic properties of the material would be more thoroughly defined[2].

With the spacings available and the frequencies which can be expected to propagate in the proposed application, the signals will be somewhat equivalent to those shown for the two closest receivers in Figure 1. Obviously the P wave break will have to be more clearly defined. That is, the relative amplitude will need to be greater, and the rise-time relatively shorter.

Geometrical Considerations

In considering the geometrical aspects of the surface and under-surface of the test material, one cannot assume a smooth flat surface, nor that the acoustic path to be tested is the straight-line path. A practical assumption, especially with a high-energy source and normal attenuation, is that the first arrival signals have traveled the shortest time path. Figure 2 represents a typical situation. The effect of surface irregularities would be small, assuming their dimensions to be small compared to a wavelength and small compared to the shortest spacing. The specified maximum value of 10 cm. becomes of major concern when 1 ft. spacings are considered. However, at 5 to 10 ft., this problem should be negligible. The bedding effect (or velocity gradient) is typical of the earth's surface and even though it often forbids the measurement of velocity of the exact surface material, it can be indicative of the under-surface materials. For example, if the source-to-first receiver travel time indicated 1200 ft/sec., and the two-receiver measurement indicated 1800 ft/sec., one could predict the actual surface material to have velocity equal to, or less than, 1200 ft./sec., and that some subsurface material had velocity equal to, or greater than, 1800 ft/sec. The depth of investigation in such a case depends on the velocity gradient and the spacings used. Expansions of this, referred to as "refraction methods", are used in seismic exploration to study certain subsurface conditions.

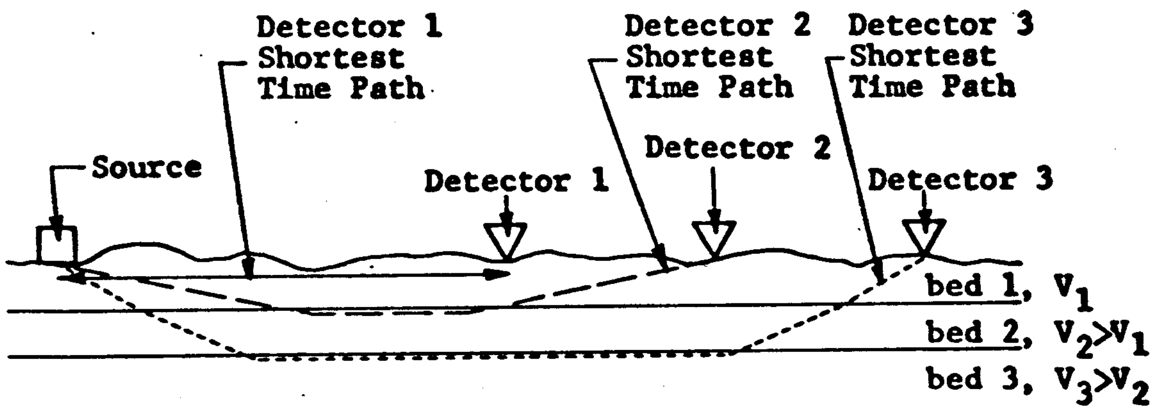

FIGURE 2

TYPICAL BEDDING EFFECT

AND SURFACE IRREGULARITIES

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1:794-4

Lateral homogenuity is assumed for the small area to be tested on the lunar surface, and thus is not considered here as to any effects on velocity measurement.

EXPERIMENTAL TESTS

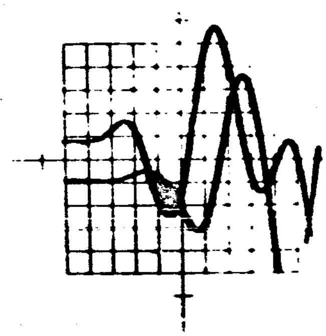
Since the lunar acoustic measurement will be made under environmental conditions including vacuum, it was considered desirable to determine whether or not this presented acoustic problems different from those in atmospheric pressures. It is known, of course, that acoustic waves will not propagate within a complete vacuum. However, even at atmospheric pressures, the proposed measurement requires that the receivers and source have intimate contact with the surface, except where an acoustic coupling medium is specifically provided. Therefore, for comparison of vacuum to atmospheric pressure, a sample of dry, very porous, low-density rock, approximately 10" by 5" x 2" was placed in a vacuum jar, with a pulsed piezoelectric source and an acoustic detector placed on opposite ends of the rock. The predominant frequency of the source was about 3 KC. Observation of the oscillographic reproduction of the detector signal indicated essentially no difference between atmospheric pressure and vacuum conditions (approximately 10^{-4} mm.Hg.). Signals observed included those traveling direct and multiple-reflected paths. These results, not unexpected, indicate that the acoustic coupling and transmission problems at hand can be considered independent of pressure below atmospheric, as long as intimate contact to the surface is maintained.

Several experimental set-ups were made in the laboratory using various repetitive type piezoelectric transducers for sources and samples of (1), dry, porous (ϕ = 27%), consolidated, limestone rock, and (2), dry, loose sand. Tests were made with source-to-detector spacings up to about 3 feet. The sources used were each resonant in the 20 to 40 KC range, but each was driven below resonance to as low as 500 c.p.s. Brush accelerometers (model BL 301) were used as detectors.

Also some testing was done with small dropped weights. Certain geophones were tested as detectors. These simple tests were made utilizing, in all cases, equipment which was readily available. None of the pulsed sources nor detectors could be considered optimally designed for this purpose, especially the detectors and receiver amplifiers. Detector frequency response curves, amplifier noise and pick-up level, and background acoustic noise level limited the quality of the result. However, it is felt that optimum design would not grossly change the picture which was indicated.

These tests were aimed toward a system having source-to-receiver and receiver-to-receiver spacings of about 1 ft. each, and a repetitive type source. These two features are the major attractions to this method. Figure 3 is an example of the resulting data from this type measurement on the aforementioned 27% Φ, consolidated limestone rock. The spacings between receivers was 1 ft.; the time scale was 200 μs/div.; the source was a barium titanate cylinder, 3 in. diameter x 3 in. length, driven with an approximate 1/2 sine-wave pulse of 600 volts peak amplitude and approximately 500 μs width. The resonant frequency of the crystal was approximately 20 KC. in the radial mode, and 30 KC. in the length mode. Its capacity was approximately .04 μfd. The frequency response of the accelerometers used is essentially linear (for constant particle velocity) from zero at 0 cps to a peak at 1500 cps and drops off rapidly above 1500 cps. However, the finite input impedance of the amplifier reduces the low frequency response even lower. Thus, the frequencies of the received signals were influenced somewhat by the detectors.

A study of this example (Figure 3) indicates some of the limitations. The "first break" choice is very questionable due to its long rise time. The possible error in making these time picks is a rather large percentage of the total Δt (approximately ±40%). Since the spacings are only a fraction of a wavelength for the predominant frequencies, and since the model itself is only fractions of wavelength, one cannot utilize the peaks and troughs for the time picks. These peaks and troughs will be influenced by the P wave, S wave, and R wave,



time →
200 μs/div.

FIGURE 3

SHORT SPACED, REPETITIVE SOURCE

Porous Limestone Sample

Using "First break" Picks

$\Delta t \cong 180\ \mu s$

R_1 to R_2 = 1 ft.

$\therefore$ P wave $V \cong \frac{1\ \text{ft.}}{180\ \mu s} \cong 5500$ ft/sec.

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1:794-5

and in this model by reflected waves (For spacings and model dimensions of several wavelengths, these waves separate in time and can be picked separately, as was shown in Figure 1).

It is rather obvious from this example that the emphasis is on higher energy especially in the higher frequency range. An improved signal-to-noise ratio would always be helpful; lower noise level would allow higher amplifier gain, and thus a more accurate time pick. Attempts to effectively propagate higher frequencies were almost hopeless with the energy available from the source.

If the material used in the example of Figure 3 had been a rather soft, low-velocity material (say, 1000 ft/sec. velocity), the arrival times would be later by about a factor of five, the frequencies which could be transmitted and detected would be down by a similar factor. Similar amplitudes could be obtained if the transmitter driving pulse is widened and the receiver frequency response is flat through this range of frequencies. Thus, if the system could be optimized for the new conditions, the presentation of signals would be similar to Figure 3 except that the time-scale would be 1000 μs/div. instead of 200. The statements in this paragraph should not be taken as completely valid; they are only indicative of the frequency effects and problems connected with various dry, porous, soils.

These laboratory tests indicated that the energy available from any feasible repetitive type source would not be satisfactory for the wide variety of conditions which may be encountered on the lunar surface. The desire would be to utilize a source which has considerably higher energy in a wider frequency spectrum than can be obtained from any known practical electro-mechanical type transducer.

Use of a dropped weight was considered and experiments indicated some advantages over the electro-mechanical type. The frequency spectrum of generated signals is automatically in the high frequency range for hard materials and low frequency range for soft materials. This is certainly desirable over a single, narrow spectrum for all materials. Also, the energy available can be rather high. However, the dropped weight method was discounted somewhat, due to its mechanical problems, problems in detecting its impact time (time-break), and its major dependence on the geometry and homogenuity of the material immediately surrounding the point of impact. Further study of this type source may be desirable, however.

Based on these efforts and on information that a small explosive source was within the realm of possible use on the space-craft, it was decided to make some preliminary field tests using dynamite caps as sources. Since the energy available here is many times greater than the previously mentioned sources, and for several other reasons which will be covered later, it was decided that longer spacings could be considered (up to 10 ft., and 10 ft.). These field tests were made in Webb County, Texas in what was considered soft, well aerated, low velocity materials. No. 6 caps were used. The receiver system used had an upper frequency limit of some 300 cps. The first test indicated (as expected) an air wave arrival before the first P wave signal arrival. Therefore, subsequent tests were made with the cap covered with loose dirt to reduce the air wave, and with source-to-receiver 1 spacing increased to 20 ft. or more. The longer spacing to the first receiver allowed P waves traveling in lower beds of higher velocity to arrive before the air wave. It was noted that the air wave produces an opposite polarity "break" from that of the ground P wave.

The tests indicated that the energy available in the cap is more than satisfactory, that the upper frequency response of the system used was adequate for the low velocity range tested, and that with higher frequency response receivers, a valid velocity measurement should be readily obtainable for the wide variety of materials to be considered. However, the problem of the gas wave to be expected in vacuum should be studied further in regards to its acoustic effect, and to the requirements for the reduction of its effect. A gas wave in a vacuum should be satisfactorily deflected merely by use of a sheet material shield. However, in air, the shield needs to be essentially immovable, either by its mass or by other means.

LUNAR APPARATUS

Mechanical Arrangement

In the proposed lunar surface measurement it seems impractical to consider spacings longer than some 10 or 20 ft. due to problems in placing source and detectors and in knowing their location. This is also limited by the source energy which can be provided. Yet, it seems impractical to consider spacings less than 1 or 2 ft. since (1) the surface irregularities become relatively large, (2) in this range the requirements on recording apparatus become extreme, and (3) for accuracy in the measurement with such short spacings, a relatively high frequency signal is necessary. Acoustic attenuation and coupling problems become extreme with increasing frequency.

In view of this and aforementioned tests with sources, it seems most practical to utilize an explosive source with spacings in the range 5 to 10 ft. for both transmitter-to-first receiver, and receiver-to-receiver. The exact value of either is not critical, except that they be known. Actually, it is not necessary (but is desirable) to know the source-to-first receiver spacing as long as the three units are in a straight line. Also, reasoning will indicate that if the distance from the source to each receiver is known, then it is not absolutely necessary that they be placed along a straight line. The assumption is made here that the source is non-directional laterally and that the material is essentially homogeneous laterally. This seems to be a reasonable assumption in this application, especially if the explosive source is used.

Thus, considerable latitude can be had in the actual location of the three components. Therefore, the locations should be chosen based on the foregoing statements and the mechanical problems in placing them. One arrangement which seems reasonable would be to locate the source at (or near) one leg of the space-craft, the first detector at (or near) a second leg of the space-craft, and the second detector on the sub-assembly which is, according to present plans, to be located some 5 ft. from the space-craft. Figure 4 indicates this arrangement. The acoustic path from the source (x) to the first receiver (R_1) by way of the legs of the S/C and the S/C itself would have to be acoustically decoupled to prevent its "short-circuiting" the desired path. The source has been shown here to be on a short spring-loaded arm. This would

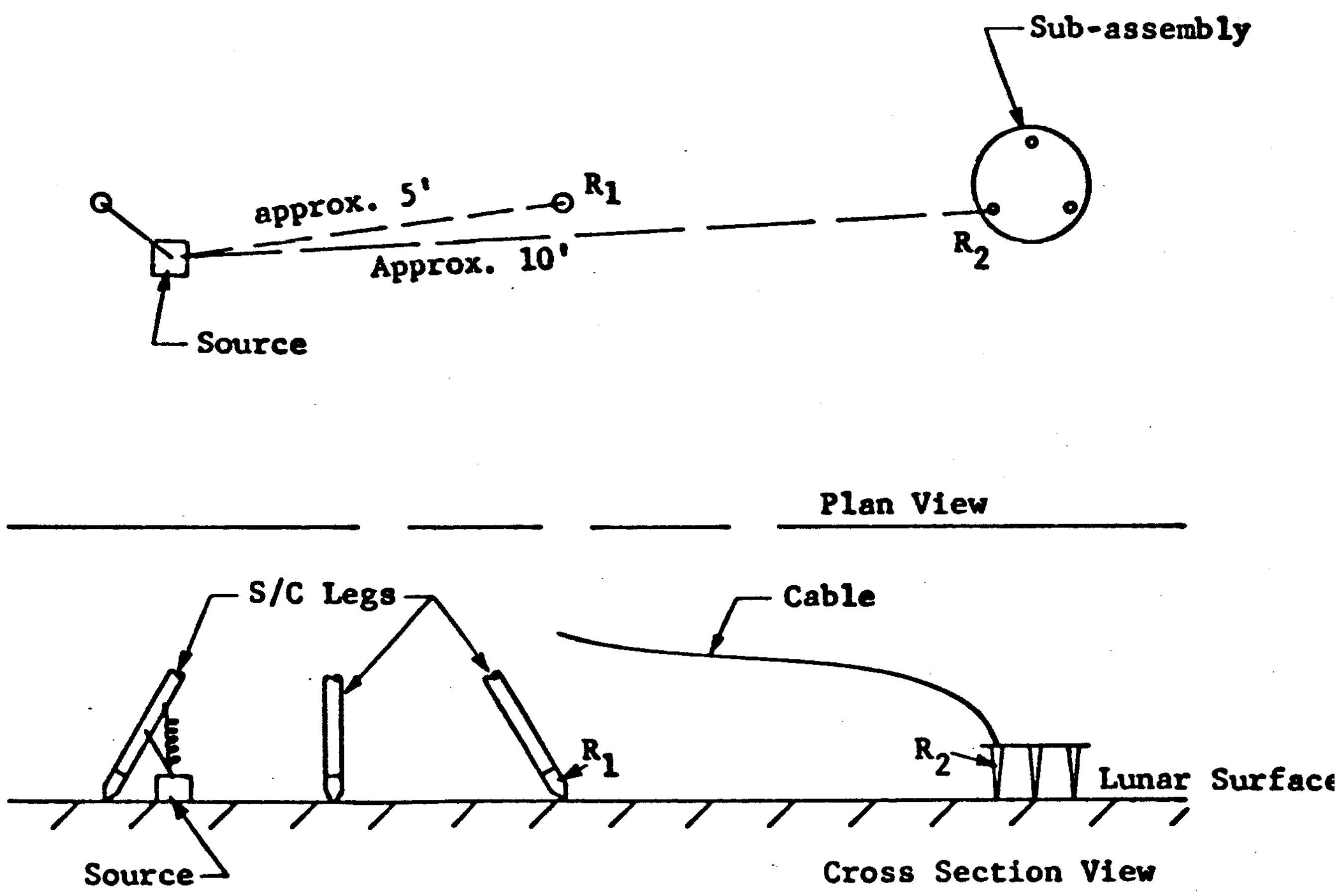

FIGURE 4

SUGGESTED ARRANGEMENT

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1:794-6

allow considerable decoupling between X and the near-by leg. R_1 could also be placed on such an arm to give more decoupling (not shown). In the case of the source, material to contain the gas wave would also be mounted on the arm. Multiple shots should be provided in the source.

Another system which should eliminate the S/C decoupling problem would be to "lobe" the source to an approximate location with trailing wire; or to place the source into location with a mechanical arm and then remove the arm. Gas wave shielding material would again have to be placed with the source. The disadvantages in the lobing would be lack of knowledge of exact location of source, need for mechanical lobing apparatus, and possibly a more involved problem in restraining the gas wave. In the placement of the source with the mechanical, removable arm method, the only disadvantage seems to be necessity of the handling apparatus. The acoustic decoupling problem would be reduced, if not eliminated, the source location would be known, wire handling would be simple, and the source and gas shielding material would be layed down with prescribed geometry.

Several other arrangements can be considered which have various advantages and disadvantages. That shown in Figure 4 is a compromise method suggested at this time.

Receiver Apparatus

In making the choice of type detector to be used one should consider the parameter to be detected. The acoustic wave which is to be detected is a wave of particle displacement. To measure the actual displacement directly would require a strain gage or capacity pick-up type detector or something similar. Such devices are not normally used, nor are they considered practical for this application. However, one can also detect the wave with a device which is sensitive to the particle velocity, or with one sensitive to particle acceleration. The relation between acceleration, velocity, and displacement (true only when single frequency (f) is present is shown in Table I.

TABLE I

Equation	Peak Values	Units
$d = d_o \sin 2\pi f t$	d_o	inches
$v = (2\pi f) d_o \cos 2\pi f t$	$6.28\, d_o f$	inches/sec.
$a = -(2\pi f)^2 d_o \sin 2\pi f t$	$39.4\, d_o f^2$	inches/sec.^{2}

d = displacement
d_o = peak displacement
v = particle velocity
a = particle acceleration

A study of the peak values shown in the table will indicate that, for constant particle displacement at various frequencies, (1) a theoretically perfect particle-velocity detector would have displacement sensitivity which is proportional to frequency and (2) a theoretically perfect acceleration detector would have displacement sensitivity which is proportional to the square of frequency. Thus, inherently, either device has reduced sensitivity to particle displacement at low frequencies, especially the accelerometer. And each inherently has high displacement sensitivity at high frequencies, again especially the accelerometer. However, since most earth materials attenuate an elastic wave roughly proportional to its frequency, it has been found desirable to use the particle velocity device which offers displacement sensitivity proportional to frequency.

The commonly used particle velocity device, the moving coil geophone (or seismometer), and the usual accelerometer (piezoelectric type) each have upper frequency limitations due to practical design problems such as mass, resonances, and damping. The upper frequency range for the typical accelerometer is well above that of interest for this application. That for the geophone, however, is normally thought of as being 500 to 600 cps. If this were the case, the geophone would be quite limited for this application. However, investigation has indicated that the geophone can be reasonably sensitive up to at least 5 KC, the typical response being approximately flat (with constant particle velocity) up to about 500 to 600 cps, and then decreasing out to at least 5 KC, with several peaks and troughs due to resonance effects. Calibration curves of geophones at the upper frequencies are not normally available due to the high accelerations encountered in the normal calibration procedures and to the fact that their normal use does not require this range. Also, utilization of geophones in the frequency range containing resonance effects would be prohibitive in most seismic work.

In the proposed application, the desire is to accomplish satisfactory response over the range 100 cps to 4 KC. The attenuation vs. frequency characteristics of most earth materials is such that it approximately cancels (or balances) the displacement sensitivity vs. frequency characteristics of the geophone over the normal frequency range of the geophone, giving a reasonable over-all frequency response. Along this same reasoning, the accelerometer is generally too insensitive at low frequencies for seismic work. For the proposed application the resonance effects on the geophone and its reduced sensitivity (to particle velocity) in the upper frequency range should not be prohibitive, since only the first arrival, first break, signal is of major importance. Hnece, the geophone should be far superior in the lower frequency range, and satisfactory in the upper range. The accelerometer should be satisfactory (and possibly superior) in the upper range; whereas, it is known to be very poor in the low frequency range (for the purpose of detecting particle displacement). Good sensitivity in the low frequency range is considered of utmost importance since the wave components in this range offer the assurance of detecting the first-arrival half-cycle signal even in low-velocity, high-attenuation materials.

In most other respects, either the accelerometer or the geophone are equally satisfactory. Either will stand the environmental conditions, either will take the impact landing, and either can be matched to amplifiers satisfactorily for the frequency range of interest. The geophone would probably have to be slightly heavier than the accelerometer, but should be as little as 3 oz. total. Based on the above considerations, it is believed that the geophone would be the desirable unit. The geophone used would desirably (but not necessarily) be of a modified design compared to that used in seismic work, based on information obtained from Mr. Hall, of Hall-Sears, Inc., Geophone Manufacturer, Houston, Texas.

It is assumed that background noises will be very low (no wind noise), thus allowing the wide frequency band compared to that in seismic work. This assumption would also allow relatively high amplifier gain, which in turn would allow a minimum source charge size. The actual limit on gain and band width may depend on the level and frequency of background noise generated by the S/C data-handling equipment.

The receiver amplifiers and data handling equipment should amplify and reproduce on earth the signals detected from the time of the source detonation until at least .1 sec. later, based on X to R_2 spacing of 10 ft. and lower limit in velocity of 100 ft/sec. The time relation between the detonation time, the first receiver signal, and the second receiver signal should be known to an accuracy of at least 12.5 μsec., based on R_1 to R_2 spacing of 5 ft., maximum velocity of 20,000 ft/sec., and accuracy of 5%. It is not suggested here that either of these velocity extremes will likely be encountered; but without more information, one cannot eliminate them.

One major requirement in connection with the detectors is that they be placed in intimate contact with the surface. Some weight or spring force to hold them in contact and upright will be necessary. They should have a cone shaped base to allow more definite contact in case of a rough or rocky surface or a soft, thin layer surface.

RE-ORDER No. 60-597

Source

With the wide velocity and attenuation ranges to be considered, it is highly desirable to have high level and wide frequency spectrum acoustic energy emitted from the source. The higher frequencies should travel satisfactorily in high velocity materials to allow the necessary short rise-time on the "first-break". Whereas, in low-velocity materials, the high frequencies are normally reduced leaving essentially only the low frequencies. In this case, however, the travel times are long and the short rise times are no longer required (for the same accuracy). The combined high energy and wide spectrum feature is characteristic of the explosive type source.

The properties of the gas wave to be expected in the environmental vacuum and the gas shield which will be necessary have not been studied thoroughly. However, it is believed that to deflect the gas wave in directions other than toward the detectors would not require unreasonable design. Experimental tests inside a large vacuum room with sample materials of dimensions several times the spacings should help in optimizing the source and shield design. Any test of this type should be made with considerations for low acoustic background.

If use of the explosive should be forbidden for reasons presently unknown, the dropped weight should be studied more seriously, for it offers a frequency spectrum which is altered

27

depending on the material impacted. In general, high frequencies are generated in high-velocity materials and low frequencies in low-velocity materials.

In view of these thoughts and previously mentioned experimental work, it can be said that the explosive type source is highly desirable. For the spacings proposed and for optimum detector and amplifier design, and with the assumed low acoustic background, it is felt that the charge size can be reduced far below that of the No. 6 cap used in field experiments. The fact that the explosive is a one-operation affair is a disadvantage in certain respects. However, this can be alleviated somewhat with multi-shots.

The actual firing time of the source is desirable information in a two-receiver system, and is necessary in a one-receiver system. This time (time-break), needs to be known (with respect to the real-time of the receiver data) to at least an accuracy of ± 5 μsec. The time-break sync. pulse can usually be added to a data channel already carrying a receiver signal and, in fact, should probably be added to both channels.

ADDITIONAL CONSIDERATIONS

Restraints on Other Equipment

The acoustic velocity measurement presents at least two restraints on other equipment. First, all equipment should be acoustically quiet during the acoustic measurement period or be decoupled from any acoustic path to the detectors. Secondly, the space-craft legs (or other similar devices) must not provide an acoustic path which will conduct detectable acoustic energy from the explosive source to the detectors, unless this path were long (in time) compared to the lunar surface path.

Additional Information

Additional information, other than velocity, may be found with the proposed system. First, as previously mentioned, 1-receiver velocity measurement compared with the 2-receiver measurement can indicate sub-surface high velocity bedding. Second, a study of amplitudes and frequencies on the two detectors offers information concerning acoustic attenuation. Third, a study of the signals recorded after surface waves have subsided may indicate reflections from underlying beds (This would require a record length up to 1 sec. or greater).

Alternate Methods

An alternate method which may be used is the single receiver measurement only. This would consist of placing the source near one leg of S/C and the one detector on the sub-assembly previously mentioned. An advantage of this would be the elimination of the problem of acoustic decoupling within the space-craft. The only decoupling necessary is that to the sub-assembly, which is accomplished by the fact that the sub-assembly is detached mechanically from the S/C. Another advantage is that the receiver and data handling equipment is now single channel, rather than double.

Several disadvantages are incurred. No information is obtained as to velocity vs. depth. Probability of getting a velocity measurement is directly dependent on reliability of the single detector, its contact to surface, and its receiver amplifier and data handling channel. Also, in case of very weak or slow rise-time first-arrival signal, the estimate of velocity is essentially non-meaningful, whereas with two receivers a rough estimte is still possible.

Another alternative which may become desirable is that of mounting the first detector on a gimble system within a small ball and lowering the ball to the lunar surface with the attached leads. This would offer optimum decoupling from the S/C. Testing would be required to study the problem of acoustic contact to the lunar surface.

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PROJECT ESTIMATES

In the suggested two-receiver method, using two geophones and a 3-shot explosive source, the following estimates and statements are made:

Accuracy of measurement, ±20% at upper velocity range
±10% at lower velocity range

Range of velocities possible, 300 to 20,000 ft/sec.

Range of velocities probable, 500 to 10,000 ft/sec.

Dimensions: Receiver 1, 1" diam. x 1-1/2" high, including cone tip.

Receiver 2, 1" diam. x 1-1/2" high, including cone tip.

Source, 1/2" diam. x 2" length

Shield (attached to source) 3" x 2" x 1/8".

Weight: Receiver 1, 3 ounces

Receiver 2. 3 ounces

Source & Shield, 1 lb.

Power: Current for firing explosive charge.

Time per operating period: Approximately .1 sec. Minimum

Number of operating periods: 3

Sample preparation requirements: None

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Manipulation requirements: Release source arm from one S/C leg. Placement of sub-assembly locates the No. 2 detector.

Data Output: Minimum Detection Level, 1 μv, 300Ω output impedance.

Peak amplitudes, 250 μv.

Frequency - 100 cps to 4 KC.

Real time data requirements: None, data storage is acceptable if accurate time measurements are included.

Commands required from S/C: Mechanical release of source from S/C leg (after S/C impact), and firing current to source (3 times).

Other requirements: Acoustic decoupling of sub-assembly, Detector 1, and source.

Source, sub-assembly, and Detector 1 should be in known physical relation.

All components to withstand lunar environment as specified by TM-33-13.

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